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Parametric optimization of a drone mounted sprayer to maximize the swath width using Taguchi design

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Abstract
Drones have revolutionized modern agriculture by offering precision and efficiency in pesticide spraying. This study evaluates the performance of a hexacopter drone for pesticide application and aims to determine the optimal combination of operational parameters to maximize swath width. The independent parameters include type of nozzle (flat fan nozzle, hollow cone nozzle and spinning disc nozzle), forward speed (2, 3, 4, 5 and 6 m s^{-1}) and height of spray (1, 1.5, 2, 2.5 and 3 m) while swath width is the performance evaluation criterion. The experiments were conducted using Taguchi L-25 orthogonal experimental design, the study identifies a combination of a forward speed of 6 m/s, a height of spray at 3 m, and a spinning disc nozzle as optimal, resulting in a swath width of 7.19 m. These findings emphasize the importance of selecting appropriate operational parameters for effective pesticide application.

Keywords: Drone mounted sprayer; operational parameters; swath width and Taguchi design

Introduction
The advent of drones has brought about a revolutionary transformation in agriculture, particularly in the domain of crop spraying. Unmanned Aerial Vehicles (UAVs), commonly known as drones, equipped with advanced spraying capabilities, are playing a pivotal role in optimizing the application of pesticides. Drones for spraying pesticides have revolutionized modern agriculture, offering precision and efficiency in crop protection. These unmanned aerial vehicles (UAVs) equipped with advanced technologies enable targeted pesticide application, minimizing waste and environmental impact.

The multirotor drones are classified into three types namely quadcopter, hexacopter and octocopter. The quadcopter of four arms has less stability during flight and small in size with less payload capacity. The octocopter is bulky in size and more expensive as compared with all available technologies. Hence, it is suggested to use hexacopter equipped with sprayer system as it is more stable during application operations as compared to that of quadcopter and it is economical than octocopter (Susitra *et al.*, 2020) [8]. The various companies are manufacturing the drone sprayers but no particular information is available regarding operational parameters of drone mounted sprayer for its better performance. Since the operational parameters will change according to the type of drone, location of area in the earth and type of crop. The set operational parameters such as forward speed, height of spray and type of nozzle need to be optimized to use drones appropriately in agriculture and allied sectors. Uniformity and the correct selection of swath width are among the most important aspects for aerial applications. Poor uniformity of spray distribution, such as a great variation of the dose across the field degrades the quality of the application, and may result in several negative aspects, such as low control of pests (Carvalho *et al.*, 2020) [3].

Taguchi designs use orthogonal arrays, which estimate the effects of factors on the response mean and variation. An orthogonal array means the design is balanced so that factor levels are weighted equally. Because of this, each factor can be assessed independently of all the other factors, so the effect of one factor does not affect the estimation of a different factor. This can reduce the time and cost associated with the experiment when fractionated designs are used.

In the current investigation, the Taguchi design used to study the influence of various operational parameters on performance of drone mounted sprayer and optimum combination of operational parameters was identified.

Materials and Methods

The drone technology experiments were conducted at UAS Raichur during 2021-22.

Drone mounted sprayer

The drone mounted sprayer comprised of several components (Fig.1) but, mainly it had basic systems like, airframe, propulsion system and command and control system. The fuselage, landing gear and arms belongs to airframe. The battery, motor, electronic speed controller (ESC) and propellers belongs to propulsion system. Radio controlled (RC) transmitter and receiver, flight controller unit, global position system (GPS) and ground control station (GCS) belongs to the command and control system.

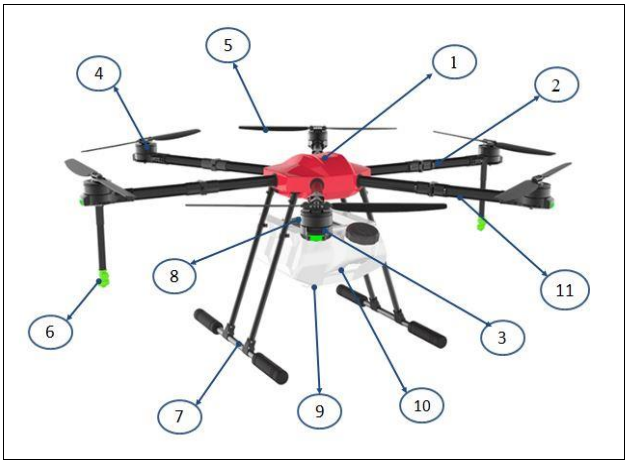

Fig 1: Components of drone mounted sprayer

Table 1: Components of drone mounted sprayer

SI. No.	Components	SI. No.	Components
1	Flight controller unit	7	Landing gear
2	Arms	8	Battery
3	BLDC motor	9	Pump
4	Electronic speed controller	10	Spray tank
5	Propeller	11	Hose pipe
6	Nozzles		

Swath width (m)

Total swath width is defined as the total discharge of material from an applicator from the leftmost to the rightmost material deposited (Houston, 2022) [5]. Total swath width is the maximum distance between the ends of ground deposits patterns, regardless of varying densities of material along the pattern. For measuring swath width three rows of white kraft paper roll were placed at parallel with each other (Fig.2). The distance between sampling lines was maintained 3 m. Red colour dye mixed with pure water was used to get impressions of water droplets on white kraft paper roll. Drone mounted sprayer was operated at different combinations of operational parameters such as Type of nozzle (N), Forward speed (FS) and Height of spray (H). The corresponding swath width was measured as maximum width (length perpendicular to the forward direction of drone mounted sprayer) up to which dense droplets were observed on white kraft paper roll (De Padua *et al.*, 2021). To ensure uniformity in speed, height and application rate, spraying was started from 10 m before sampling line and stopped at 10 m after sampling line to get better results.

Fig 2: Operating drone mounted sprayer on white kraft paper roll to measure swath width

Taguchi design

Taguchi method can optimize only single response with respect to multiple independent variables. In present study, Taguchi orthogonal array of L25 configuration was constructed in Minitab. 19 software considering type of nozzle (flat fan nozzle, hollow cone nozzle and spinning disc nozzle), forward speed (2, 3, 4, 5 and 6 m s^{-1}) and height of spray (1, 1.5, 2, 2.5 and 3 m) at five levels each (Table 1). Since Taguchi method utilizes orthogonal arrays, the levels of three factors should be same. The levels of flat fan nozzle and spinning disc nozzle were selected as dummy treatments. Measured values of performance parameter swath width was recorded and given as result inputs for further analysis. In Taguchi method, the experimental values of various responses are further transformed from signal to noise (S/N) ratio (Sudeesh *et al.*, 2018) [7]. The goal was to optimize the combination of independent parameters which will maximize the swath width. Hence, S/N ratio for "Larger is Better" was set for swath width in Taguchi method using following model equations.

Larger is Better

$$S/N = -10\times \text{Log}_{10} (\text{sum } (1/\bar{y}2) \div n)$$

Where,
$\bar{y}^2$ = Square of mean values of signal
n = Number of readings
s = Standard deviation

Results and Discussion

Effect of operational parameters on swath width

The swath width was recorded at different levels of operating parameters *viz.* Type of nozzle (N), Forward speed (FS) and Height of spray (H) and tabulated in Table 1 as per the experimental combinations obtained from Taguchi L-25 orthogonal design. The swath width observed was in range of 2.53 to 7.22 m during the experiments. The maximum swath width 7.22 m was observed at combination spinning disc nozzle, 3 m height of spray and 3 m s^{-1} forward speed. The minimum swath width 2.53 m was observed at combination hollow cone nozzle, 1 m height of spray and 5 m s^{-1} forward speed.

Table 1: Taguchi L-25 orthogonal experimental design

Exp. No	Type of nozzle	Forward speed (m s^{-1})	Height of spray (m)	Swath width (m)
1	Flat fan type	2	1	2.92
2	Flat fan type	3	1.5	3.88
3	Flat fan type	4	2	4.79
4	Flat fan type	5	2.5	5.41
5	Flat fan type	6	3	6.25
6	Flat fan type	2	1.5	3.98
7	Flat fan type	3	2	4.52
8	Flat fan type	4	2.5	5.29
9	Flat fan type	5	3	6.48
10	Flat fan type	6	1	2.86
11	Hollow cone nozzle	2	2	3.75
12	Hollow cone nozzle	3	2.5	4.52
13	Hollow cone nozzle	4	3	4.78
14	Hollow cone nozzle	5	1	2.53
15	Hollow cone nozzle	6	1.5	3.14
16	Spinning disc type	2	2.5	6.54
17	Spinning disc type	3	3	7.22
18	Spinning disc type	4	1	3.95
19	Spinning disc type	5	1.5	4.53
20	Spinning disc type	6	2	5.91
21	Spinning disc type	2	3	7.18
22	Spinning disc type	3	1	3.89
23	Spinning disc type	4	1.5	4.61
24	Spinning disc type	5	2	5.85
25	Spinning disc type	6	2.5	6.23

The effect of operational parameters *viz*. Type of nozzle (N), Forward speed (FS) and Height of spray (H) on swath width (SW) is portrayed in Fig. 3. It was observed that the swath width was increased as height of spray increases. This may be due to the as drone sprayer's height increases above the target surface, the spray particles or droplets have more time to disperse and cover a wider area before reaching the ground. This can result in an increased swath width, the higher the flight altitude, the wider the swath width as spray droplets released from the nozzle are diffused (Zhang *et al*., 2017, and Martin *et al.*, 2019) [10, 6]. The velocity discrepancy from the middle to the outwards of the down-wash airflow led to an expanding tendency of airflow and thus an expansion of the spraying width. The spraying width was basically proportional to the flying height (Zhilun *et al*., 2018) [11]. The swath width was found non-significant with the forward speed. These results were in agreement with the statement of Martin *et al*. (2019) [6].

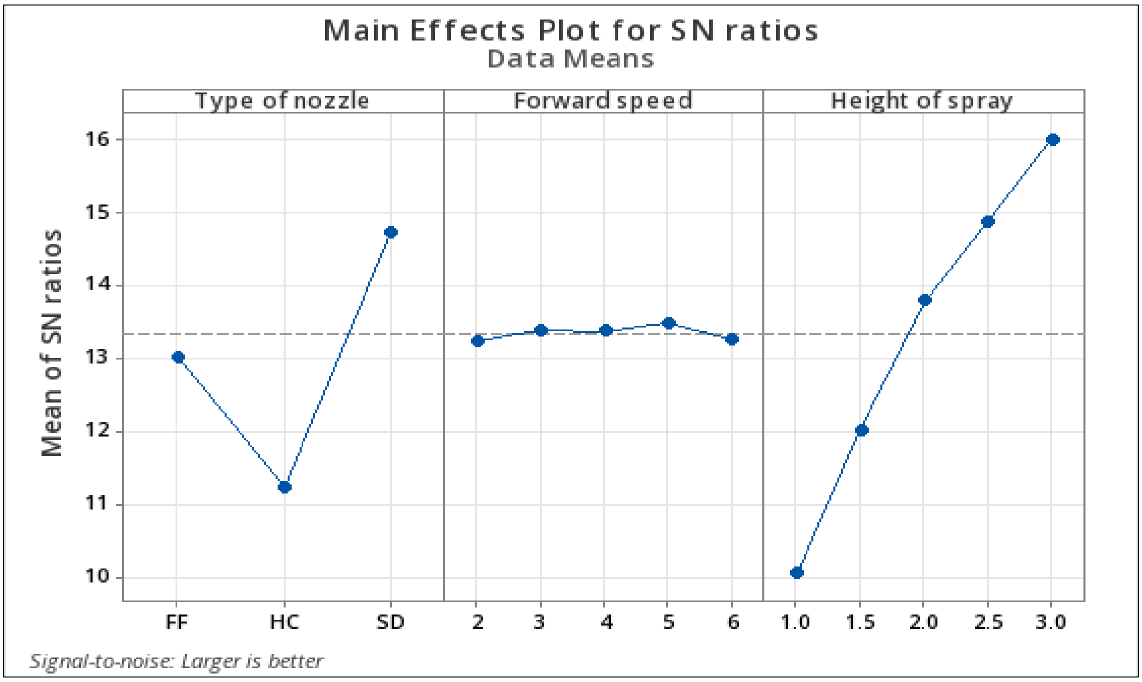

Fig 3: Main effect plot for SN ratios (Larger is better) for swath width (SW)

The Pareto chart (Fig. 4) was generated to indicate most significant parameter among selected independent variables based on the standardized effect values at 5% level of significance. It was found that the type of nozzle has more significant effect followed by height of spray. The forward speed had non-significant effect on swath width.

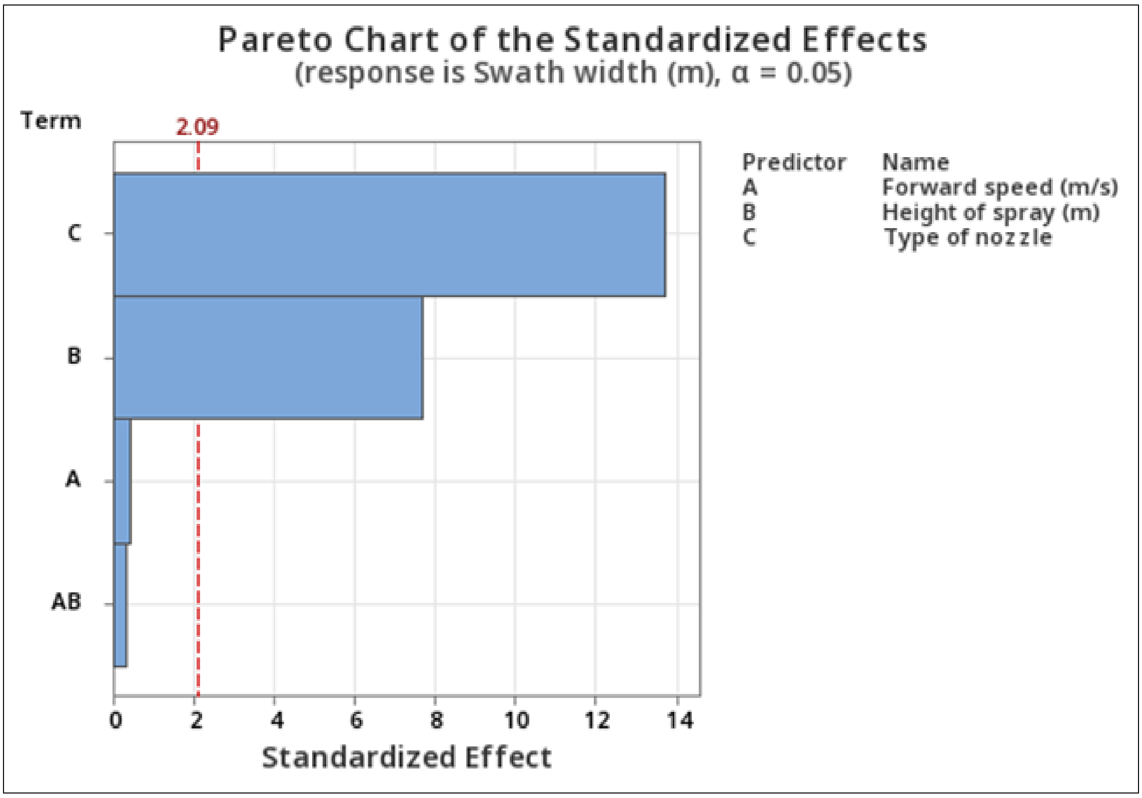

Fig 4: Pareto chart of the standardized effect of type of nozzle, forward speed and height of spray on swath width

Application of response optimizer to optimize operational parameters

The swath width was optimised for the goal maximum is better. The maximum swath width of 7.19 m was observed. Composite optimum combination plot was prepared by considering maximum swath width. It was found that forward speed at 6 m s^{-1}, height of spray at 3 m and spinning disc nozzle was the optimum combination for swath width with desirability of 0.9954 (Fig.5).

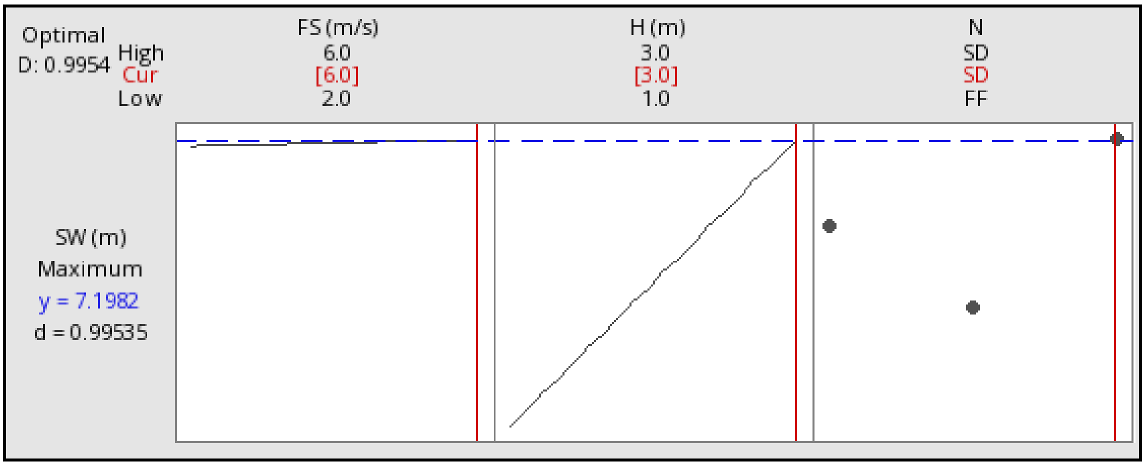

Fig 5: Composite optimization plot

Conclusion

The experiments were conducted to find optimum combination of operational parameters to maximize the swath width of drone mounted sprayer according to Taguchi L-25 orthogonal experimental design. Taguchi analysis of parameters revealed that the type of nozzle has more significant effect on swath width followed by height of spray. The forward speed had non-significant effect on swath width. The maximum swath width 7.19 m was observed at combination forward speed at 6 m s^{-1}, height of spray at 3 m and spinning disc nozzle.

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